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Air Pollution. Appendix G. Mathematical Model for Urban Diffusion of Carbon Monoxide from Motor Vehicles

NATO Committee on the Challenges of Modern Society, Brussels (Belgium)

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AIR POLLUTION

APPENDIX G - MATHEMATICAL MODEL FOR URBAN DIFFUSION OF CARBON MONOXIDE FROM MOTOR VEHICLES

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POLLUTION ATMOSPHERIQUE

APPENDICE G: MODELE MATHEMATIQUE POUR LA DIFFUSION URBAINE D'OXYDE DE CARBONE DE CAGE DES VEHICULES MOTORISES

COMITE SUR LES DEFIS DE LA SOCIETE MODERNE

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MATHEMATICAL MODEL FOR URBAN DIFFUSION OF CARBON MONOXIDE FROM MOTOR VEHICLES

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MATHEMATICAL MODEL FOR URBAN DIFFUSION OF CARBON MONOXIDE FROM MOTOR VEHICLES

Abstract

The need for a tool capable of predicting air quality changes as a consequence of measures taken to control emissions from mobile sources, prompted FEEMAS to verify the applicability of a mathematical model for CO diffusion to the city of Turin where an extended network of air quality monitoring stations is available.

The model input data (traffic hourly distribution and its qualitative and quantitative composition, specific emissions, meteorological parameters) were obtained through surveys and experimental determinations. Hence, they represent the true urban area conditions referred to town arterial plan, traffic and meteorological conditions.

The output data were checked on the base of CO concentration levels observed at the Monitoring Station of the FIAT Network.

Substantially, the model proved suitable to simulate the pollution levels induced by motorized traffic in a town like Turin: namely, the trends of calculated and observed levels are quite similar.

From this point of view, the model performance is satisfactory, even if

some discrepancies are noticed.

The model is quite versatile too, taking into account the wide variety of input parameters and their uncertainty degree.

Checked the model outputs validity, a peculiar data processing has been made, assuming the ipothesis of establishment of a pedestrianized area in the old town center of Turin.

An average 90% reduction of pollution levels was calculated within such area, and no reduction or significant benefits was found for the adjacent areas, with traffic volume at par.

MATHEMATICAL MODEL FOR URBAN DIFFUSION

OF CARBON MONOXIDE FROM MOTOR VEHICLES

1. Application of a Mathematical Model to the city of Turin

Among its research activities, FEEMAS undertook a study for the development of a tool permitting the prediction of changes in the urban center air quality as a result of actions aimed at motor vehicle emission control.

As the investigation subject, Turin was chosen for which FIAT set up an extended network for air quality monitoring that permits the truth of the results obtained from the simulation to be correlated.

The structure of the network is shown in Fig. 1 and detailed in App. 1.

Furthermore, Turin was chosen because, due to its urban characteristics it is a typically representative investigation sample.

In fact, over a 130 km^2 area, the following zones may be defined: central, consisting of the old town center where business activity is prevailing, and a peripheral, prevailingly industrial zone.

The old town center is characterized by narrow, one-way streets and is connected to the residential and industrial districts by multi-lane

Fig.1

TURIN AIR POLLUTION MONITORING NETWORK

FIAT STATIONS

1_V. LAGRANGE
2_MIRAFIORI
3_FERRIERE
4_MOLE ANTONELLIANA
5 _ PORTA NUOVA CO
6 _ P.za STATUTO CO
7-14_Pb SAMPLING POINTS

avenues. The through-ways on which most of heavy traffic travels are tangent to the urban center.

The total length of the arterial network is 1037 km.

From the traffic density standpoint Turin is one of the European cities with the highest motorization index (2.6 inhabitants per vehicle).

The total of the vehicles on the roads is given by 550,000 passenger cars, and light vehicles, 2,000 public transport vehicles and 25,000 heavy duty vehicles.

Due to the street network pattern and vehicle density, traffic is characterized by low commercial speeds (20-25 km/h) and frequent stops.

The pollution field due to this traffic situation may be summarized in Table 1 :

TAB. 1 - Pollutants Emissions in Turin Urban Area

Source	Fuel type	Consumption tons/year	Emissions of CO tons/year	Bibl. Ref.
Space heating systems	Heavy fuel oil	560,000	364	First report on the Italian Country Environmental Situation A73 Tecneco
	Light fuel oil	600,000	520	
Industrial power plants	Heavy fuel oil	440,000	277	
Automobiles	Gasoline	230,000	112,400	

2. Selection of the Model Adaptable to Turin

In order to have available a reliable tool for the simulation of the pollution field from the above emissions, as the first step a survey was carried out of the models already finalized by Research Bodies and Institutes operating in this field.

Three types of mathematical models for the study on pollutants diffusion in urban centers were identified :

- macromodels of extraurban diffusion
- mesomodels of urban diffusion
- micromodels of local diffusion

The extraurban diffusion macromodels study the diffusion of the polluting masses over great distances taking into account, for the evaluation conditions of a given area, the contribution from sources located in the adjacent external areas.

The most significant applications of these types of model were directed to the evaluation of air quality in large American cities where the presence of heavy pollution sources in the areas surrounding the cities (by passes, elevated roads, highways, large airports with very

intense traffic) leads to consider the non-negligible contribution of these sources to urban center pollution.

The urban diffusion mesomodels consider the polluting sources located inside the urban areas.

As a complement to the above models, the local diffusion micromodels permit an evaluation of the pollution levels affecting some restricted urban areas, such as street canyons, heavy traffic intersections, etc, in order to assess the actual pollution levels sustained by the people staying at length in such areas.

Furthermore, these last models enable the investigators to study, the local consequences of possible traffic control provisions such as the installation of traffic lights, the establishment of one-way streets, etc.

In consideration of the urban configuration of Turin and keeping in mind the scope of the work to be undertaken, a synoptic mesomodel was chosen for this city.

A similar simulation scheme was already set up by the Stanford Research Institute for some American centers.

The use of a macromodel was rejected in view of the fact that as regards Turin the outskirt pollution sources are not significant and, in any case, not such as to have an effect on the urban area pollution.

Also the micromodel was discarded on the grounds that it does not offer the possibility of characterizing the overall pollution picture of the city as its action is limited to localized pollutions.

3. Fundamental Elements of the Mesomodel

The selected model calculates the distribution of carbon monoxide pollution in the urban area, at ground level and on an hourly basis.

The elements on which data processing is based are :

- The recording points (receptors) where pollutant concentration is calculated
- The amount of emissions from the vehicles on the road
- Meteorological parameters
- Correlation equations of the input values

This group of elements which enter directly in model formulation is supplemented by the host of data collected by the monitoring stations.

This permits the calibration of the model and a verification of the calculated data, i.e. ultimately, the reliability of the selected

calculation method.

3.1 Receptor Points

These points represent the stations at which CO concentrations are calculated.

They are identified through the subdivision of the urban areas into telescopic squares with side of 600 m city edge areas and 200 m (central areas) respectively.

The receptor points, whose total is about 500, are located at the center of each square.

The subdivision grid is oriented NS-EW and includes the area limited by the city municipality boundaries.

3.2 Computation of Active Emissions for Pollution Calculation at Receptor Points

The pollution calculated at a receptor point is given, logically, also by the emissions coming from up wind areas.

The contribution of such emissions will be certainly more significant for the sources located in proximity of the receptor as the diffusion effect of the polluting masses are more limited. Conversely, the contribution from sources located farther away will be less significant

as in this case the diffusion phenomena may develop more completely before the polluting masses are carried to the receptor point by wind.

In-depth studies on this subject led to the development of an oriented receptor (Clarke Gifford) which encloses an area whose emissions can actually contribute to receptor pollution.

The receptor, shaped and positioned as shown in Fig. 2, consists of 7 annular logarithmic segments of which :

- The first, extends from the receptor point to 125 m roughly comparable to the size of a city block.
- The second, third and fourth reach 250,500 and 1000 m respectively from the receptor point.

  These first four segments embrace an angle of 45°.
- The fifth, sixth and seventh segments are at 22°30' and extend to 2,4 and 8 km from the receptor point.

The receptor axis is positioned in line with the prevailing wind direction. For calculation purposes it is assumed that only the emissions inside the receptor can contribute to the pollution recorded at the receptor point (see Fig. 3).

3.3 Metereological Parameters

The meteorological parameters which are required to calculate the

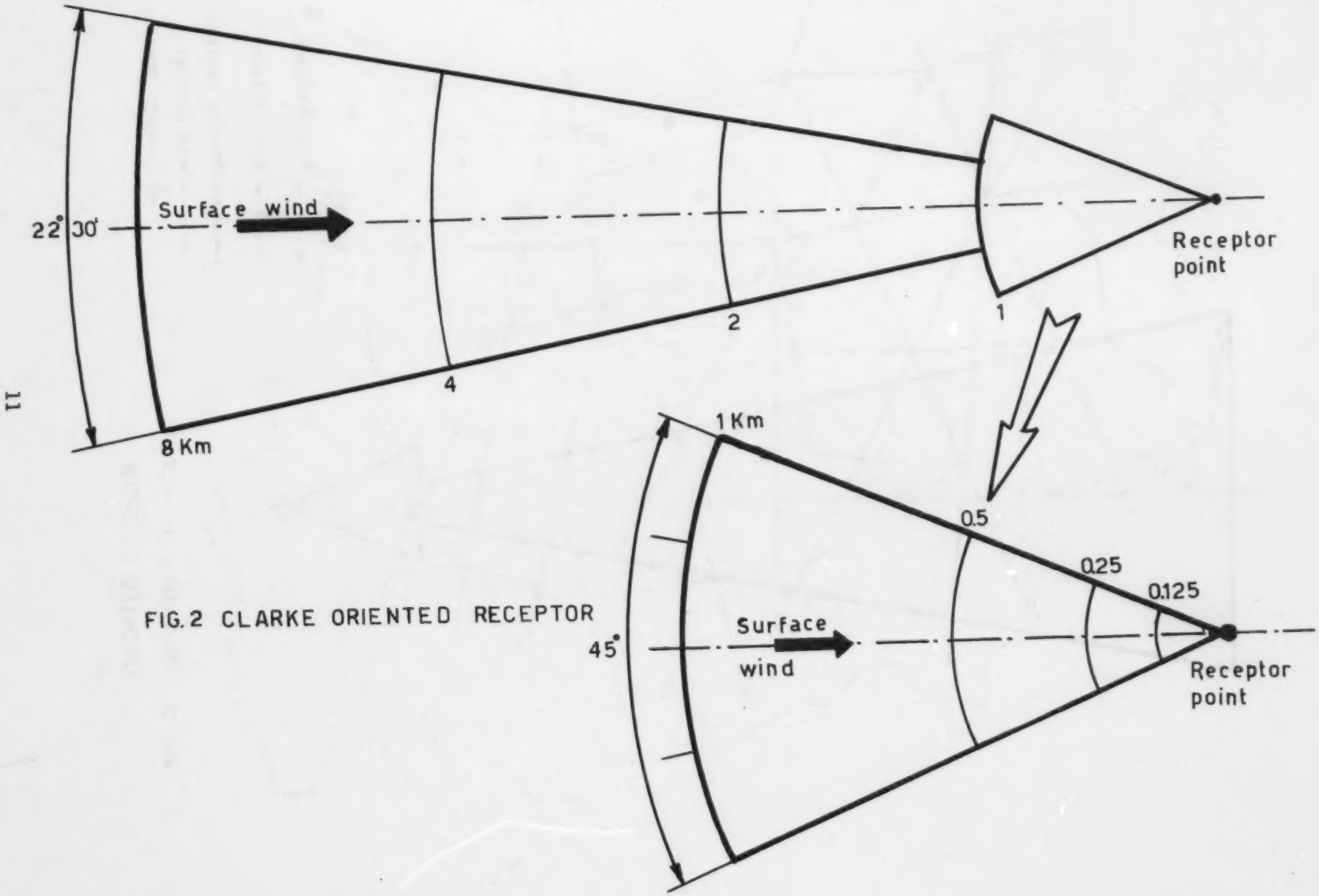


FIG. 2 CLARKE ORIENTED RECEPTOR

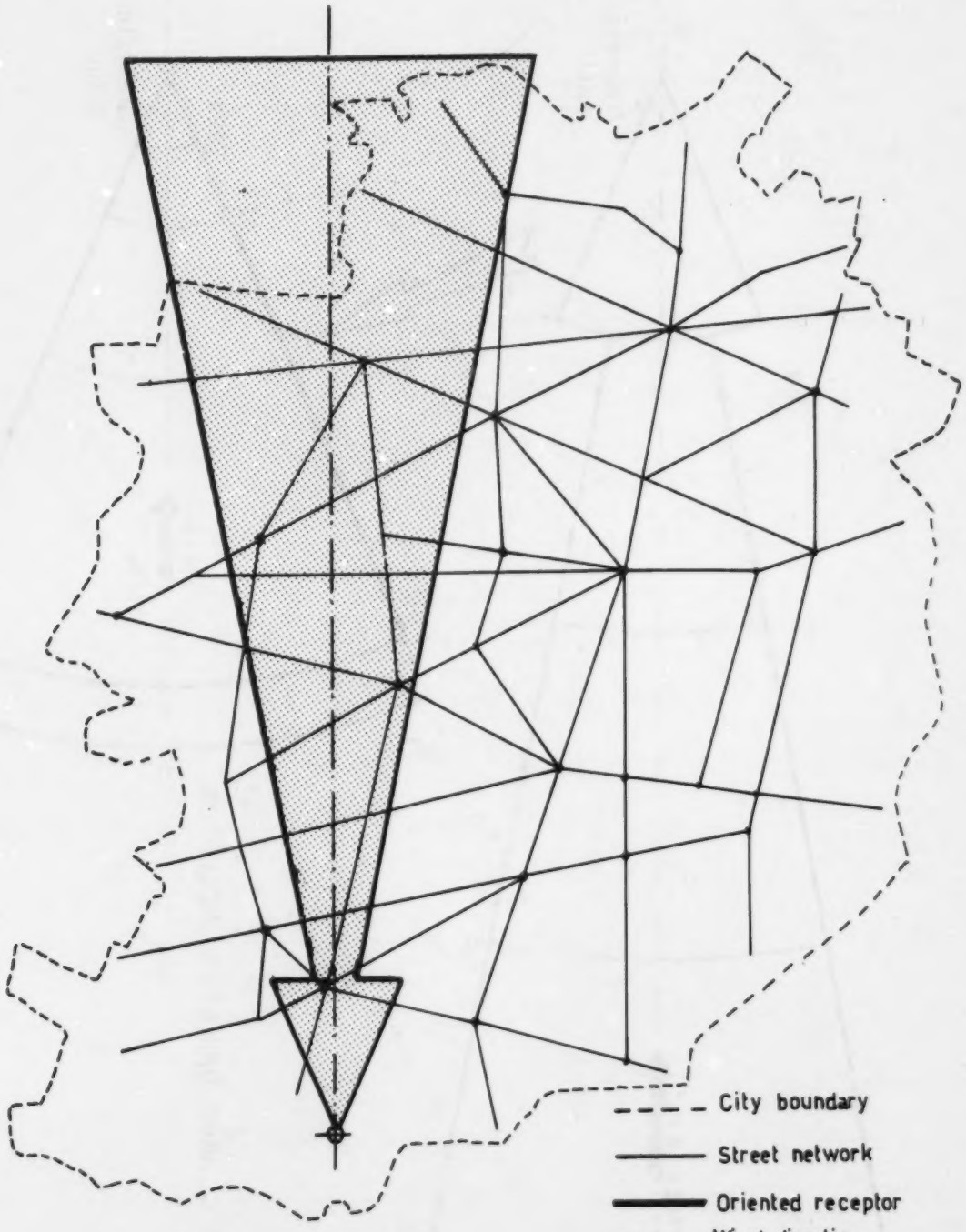


FIG. 3 POSITIONING OF CLARKE ORIENTED RECEPTOR

concentration at a receptor point are the following :

- Wind direction, speed and variability
- Mixing depth (HMD)
- Atmospheric stability

Wind direction plays an important role inasmuch as, in regard of the pollution measurable in a given area, it may contribute substantially to transport pollutants from heavily polluted nearby areas.

On the contrary, wind speed plays a direct role in the diffusion phenomenon, whereby a relationship of inverse proportionality exists between wind speed and pollutants concentration.

The combined action of wind speed and direction cause the turbulent motions which characterize the atmospheric conditions at low altitudes.

Other factors enter into play, such as the intensity of solar radiation which causes ascending convective air streams, and mechanical turbulence caused by eddies induced by the wind striking natural and artificial obstacles in its path near the ground.

This means that in a built area, due to the non-uniform presence of buildings and to the urban configuration itself, much diversified micrometeorological situations occur, quite different from the standard conditions which may be recorded in the airports.

Acquiring an in-depth knowledge of such situations is rather difficult.

On the other hand, the use of data recorded in areas which are not significant for the urban center may induce misleading results.

The value of height of the mixing depth is linked both to the atmospheric conditions (solar radiation, cloud cover, turbulence) and, though indirectly, to the presence of more or less extended built up areas.

In fact, the heat island effect induced by built-up areas on local meteorological conditions is well known.

HMD exhibits even substantial variations during the day span, the minimum values occuring in the first hours after sunrise, with the maximum values in the hours when solar radiation is highest.

It ensures that, excepting particularly critical situations, the conditions which favor the maximum pollution levels occur in the first morning hours.

Recording of the actual HMD values is performed by radiosonde soundings which measure the vertical temperature gradient or, alternatively, with more sophisticated instruments (Lidar technique).

Atmospheric stability represents a parameter which synthetizes the

atmosphere turbulence condition associated with the wind and meteorological conditions assessed.

The computations of atmospheric stability classes for the evaluation of diffusion parameters to introduce in the data processing have been made on the base of Brookhaven method.

Climatic stability class rating is based on wind direction changes over the time period considered. Practically, the following classification is obtained:

Directional shifts	Class
> 90°	A
45° to 90°	B_2
15° to 45°	B_1
Below 15°	C
Negligible or none	D

Ratings A and B_2 refer essentially to convective changes and are associated with marked instabilities. Class B_1 represents a combination of convective and mechanical turbulences, and is associated with moderate instabilities.

Class C is associated with mechanical turbulences and represents neutrality; class D indicates no turbulence, that is, stability.

Upon the climatic stability classes so defined depend the diffusion vertical (σ_z) and lateral (σ_y) parameters which are directly introduced in the equation of pollutant diffusion into the atmosphere.

3.4 Basic Equations for Correlation of Input Data

a) Gaussian Diffusion Equation

The generalized equation for the gas diffusion from a point source, assuming perfect reflection from the ground, was worked out by Gifford from the Gaussian equation as follows:

$$C = \frac{Q}{\pi \cdot \sigma_y \cdot \sigma_z \cdot u} \exp\left(-y^2/2\sigma_y^2\right)$$

where:

C = Ground-level CO concentration

Q = Source strength

U = Average wind speed

Y = Lateral (crosswind) distance from the plume axis

$\sigma_y \sigma_z$ = Lateral and vertical standard deviations (see Fig. 4-5).

Subsequent integration and processing allow the definition of an equation for diffusions from area sources:

$$\left(\frac{C}{Q_A}\right)_{ij} = \frac{0,8}{u\, a_{ij}} \left(1 - b_{ij}\right)^{-1} \left(r_{i+1}^{1-b_{ij}} - r_i^{1-b_{ij}}\right)$$

where r_i and r_{i+1} are, respectively, the distance to the upwind and downwind boundaries of the ith segment of the oriented receptor. Q_A is the emission strength of area A; a and b are diffusion parameters as functions of distance (i) and of atmospheric stability class (j).

b) Box Diffusion Equation

The box diffusion equation applies when it may be assumed that the pollutant is diffused uniformly along the vertical, i.e., for sources that are sufficiently far from the receptor.

In this case, CO concentration is calculated from:

$$\left(\frac{C}{Q_A}\right)_i = \frac{r_{i+1} - r_i}{u \cdot h}$$

where h is the depth of the layer into which the pollutants are uniformly mixed..

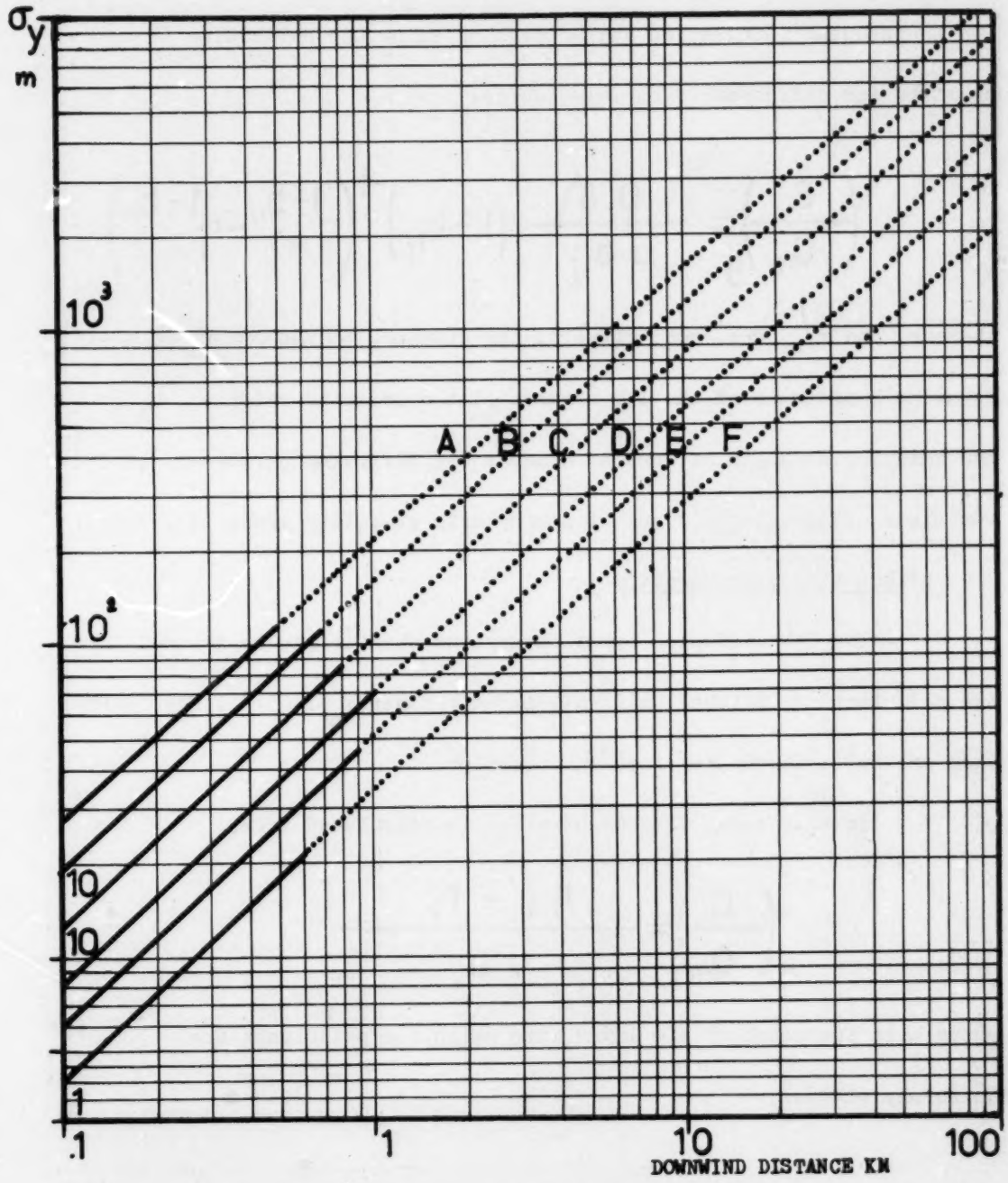


Fig.4 - CROSSWIND STANDARD DEVIATION

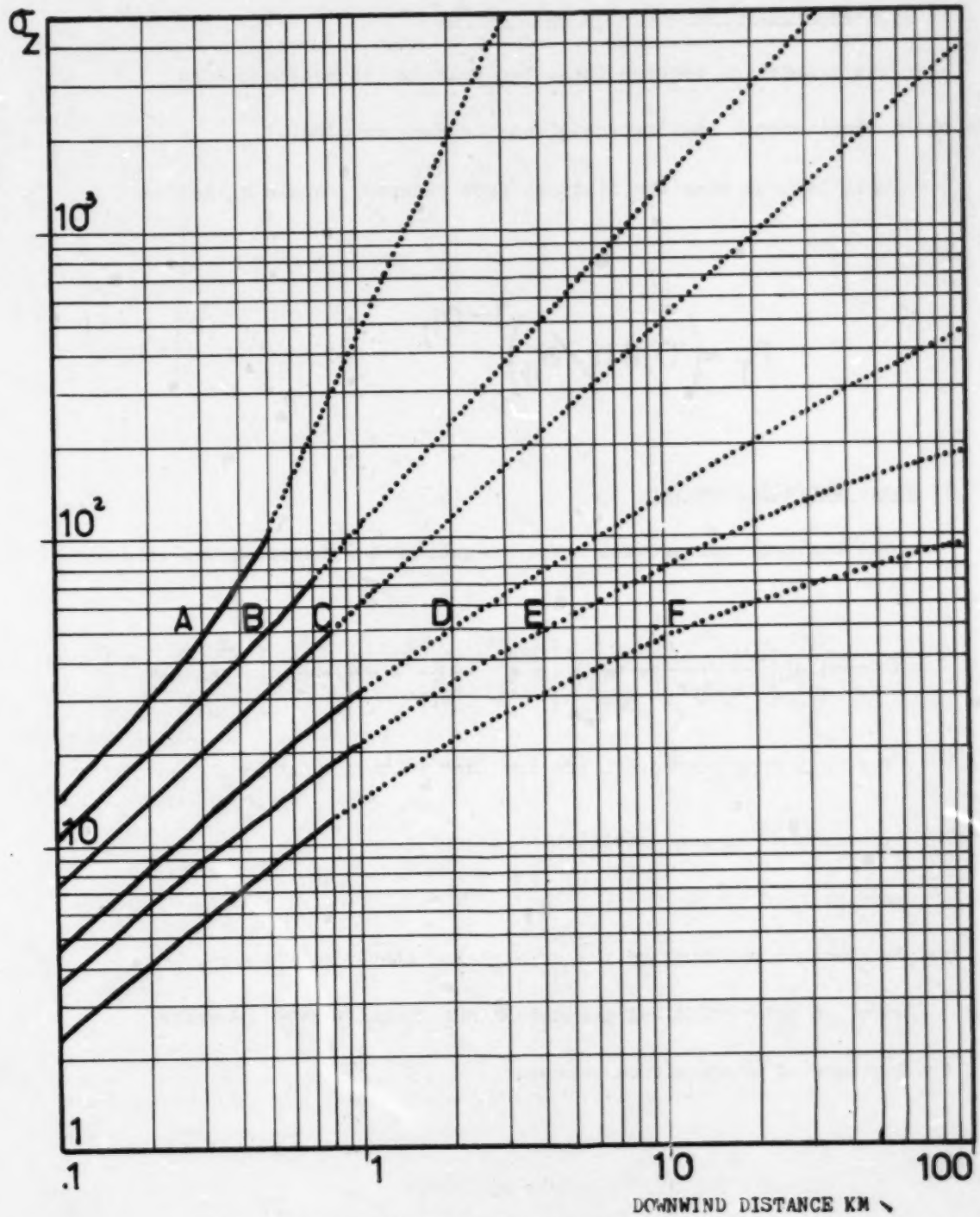


Fig. 5 - VERTICAL STANDARD DEVIATION

c) Transition from Gaussian to Box Models

The transition between these two calculation models occurs when their simultaneous application gives the same results.

This happens when the distance from receptor equals r_T defined as:

$$r_T = \left(0{,}8\, h / a_{ij} \right)^{1-b_{ij}}$$

d) Basic Overall Equation

The basic overall equation for computing CO concentrations is :

$$C = \frac{1}{U} \left\{ \sum_{i=1}^{N-1} Q_i \left[\frac{0{,}8 \left(r_{i+1}^{1-b_{ij}} - r_i^{1-b_{ij}} \right)}{a_{ij} (1-b_{ij})} \right] + Q_N \left[\frac{0{,}8 \left(r_T^{1-b_{ij}} - r_N^{1-b_{ij}} \right)}{a_{ij} (1-b_{ij})} + \frac{r_{N+1} - r_T}{h} \right] + \sum_{i=N+1}^{8} Q_i \left[\frac{r_{i+1} - r_i}{h} \right] \right\}$$

The following parameters are included in this equation:

C = Carbon monoxide concentration at receptor

U = Average wind speed

ij = Constants identified by the atmospheric stability classes, bound to meteorological parameters and distance from receptor

r = Distance of sources from receptor

ij = Indexes identifying, respectively, the urban area zone considered and the existing climatic stability class.

h = Mixing depth

Q_i = Vehicle park emission strength referred to the i^{th} segment

Q_N = Vehicle park emission strength referred to the N^{th} segment area within which the transition radius is located.

4. Acquisition of Input Parameters for the City of Turin

Application of the mathematical basic equations calls for the acquisition of the following parameters:

- Meteorological, in the Turin area
- Emissions, from vehicle park

Among the meteorological parameters the following must be known, in particular :

- Wind speed and direction
- Mixing depth
- Atmospheric stability class

and, among the emission parameters:

- Traffic flow distribution and arterial network development
- Quantities of specific emissions from vehicles in circulation.

4.1 Meteorological Parameters

Anemological parameter data, wind direction and speed, wind shifts about the prevalent blowing direction, have been provided by the FIAT Air Quality Control stations (Fig. 6a,b,c).

As is apparent from the roses plotted for the Ferriere, Lagrange and Mirafiori monitoring stations, the direction of prevailing winds over the urban area (NW-NE and around south respectively) are such as to transport pollutant emissions to the city center.

This anemological situation is prompted by the orographic position of the urban area which is located in a level area close to flanking hills and at the convergence of numerous alpine valleys (see map).

The wind velocities recorded are definitely quite low (1-2 m/s): stronger winds are absolutely random and only during high turbulence events.

No statistical data on mixing depth, as well as the astronomical and meteorological parameters for its calculation, are available for city of Turin: those used here were provided by the Atmosphere Dynamics Institute of the Brera (Milan) Astronomical Observatory.

The adoption of the typical Milan parameters for the city of Turin is justified by the geographical, climatological and anemological

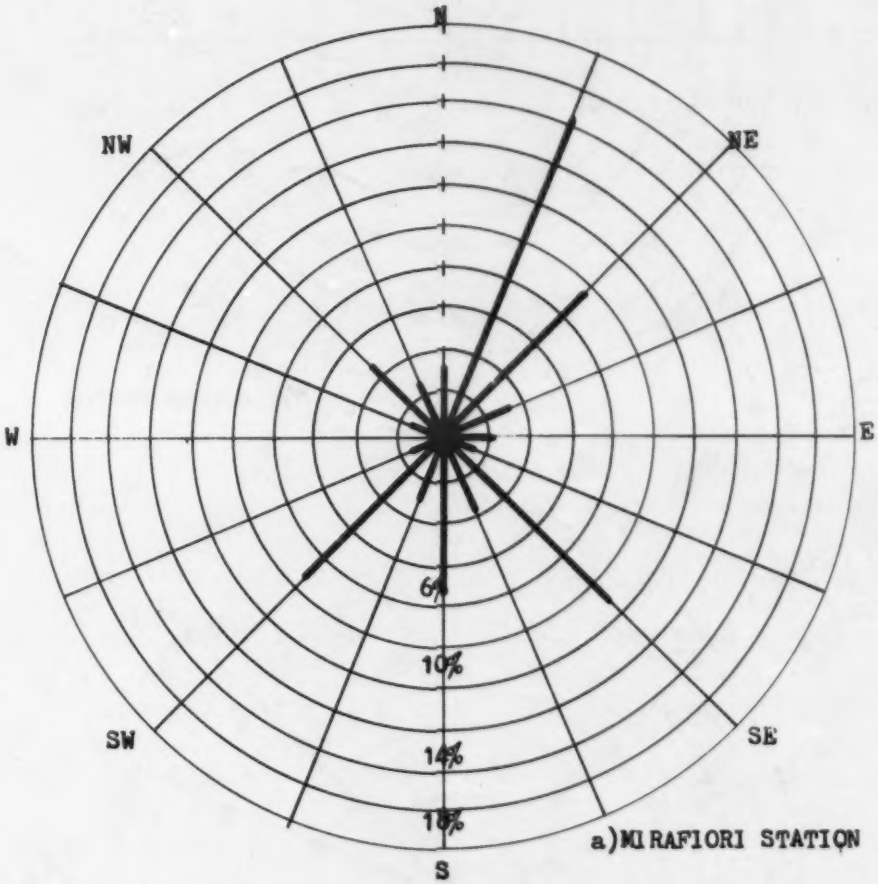
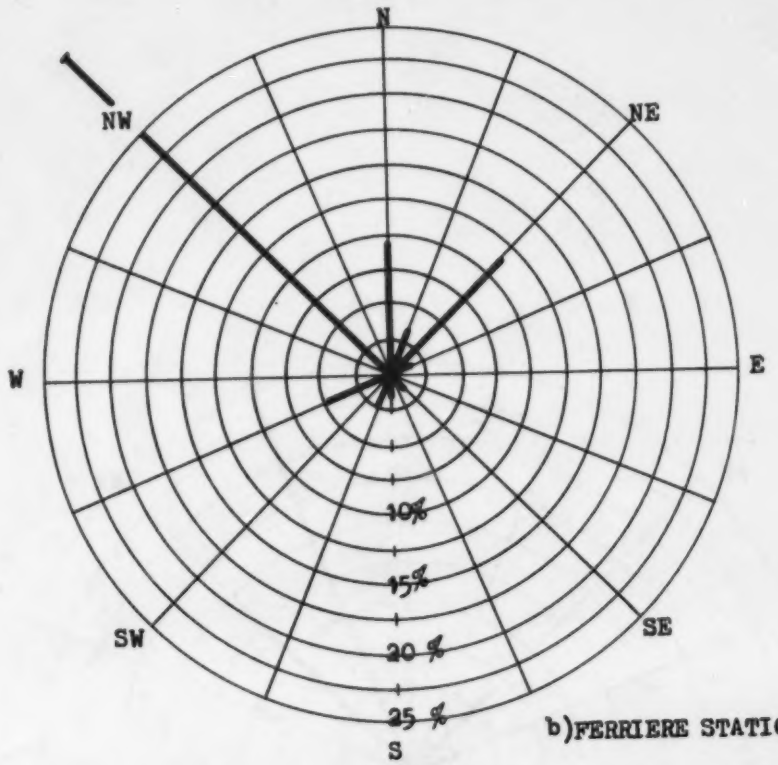
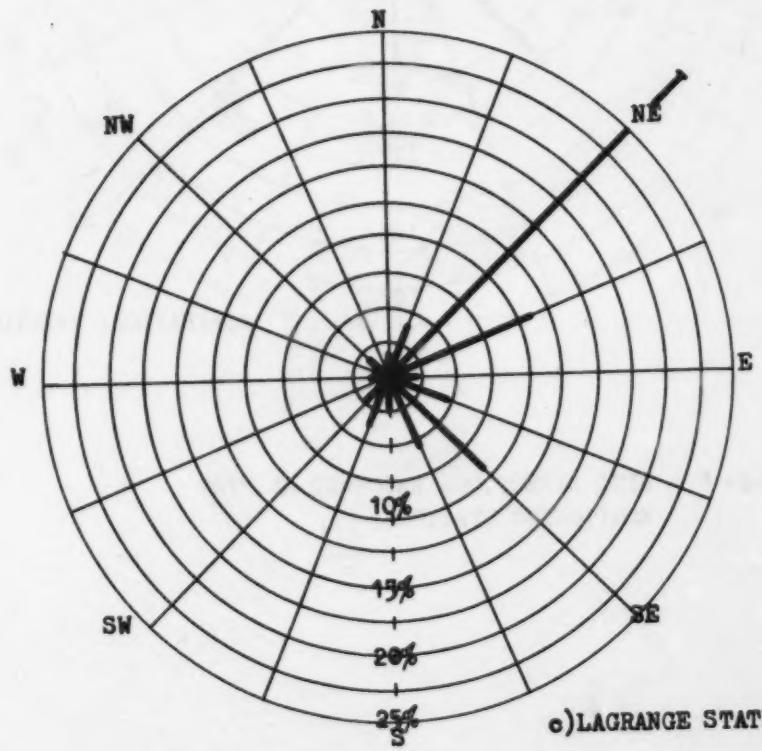


Fig. 6 - WIND DIRECTIONS RECORDED AT FIAT MONITORING STATIONS.



b)FERRIERE STATION



c)LAGRANGE STATION

similitudes between the two cities.

The data used for calculations, represent:

- Monthly averages

- Seasonal averages

- Annual averages.

As evidenced by the tabulated values the HMD is at its minimum values in winter, particularly in the December-January period.

These values may be even more limited on some particular days in winter time, or, the occurrence of low-altitude thermal inversions may produce stagnation phenomena that coincide with maximum pollution levels at ground caused by the impossibility of pollutants diffusion beyond the inversion layer.

Such events, which occurred exceptionally, for instance, in London in 1954 are extremely difficult to simulate as they escape the rules of mathematical model analysis because of pollutant accumulation factors which, obviously, are hardly reproducible.

However, it is a matter of sporadic episodes no account of which should be taken if the intention is to characterize a given area from the general aspects of air pollution.

Regarding the atmospheric stability classes, the Brookhaven method was chosen for the mathematical model input data, its classification principles being based on the amount of wind shifts about the prevalent blowing direction.

A statistical evaluation of the stability classes recorded in Turin during the winter- summer seasons has evidenced that prevailing classes are A in winter (i.e., when pollutant diffusion is at its worst) and D in summer (i.e. when such diffusion is at its best).

The diffusion parameters introduced in the equation of para. 3.4 are the direct consequence of such diversified atmospheric stability conditions.

The values for these parameters inferred from Calder's theory.

4.2 Emission Parameters

4.2.1 Traffic

Vehicular flow distribution parameters were deducted from the city traffic through an investigation conducted with the aid of direct transit recordings in sampled areas of the arterial network.

The investigation was aimed at acquiring data on the hourly

distribution of traffic flow in the streets and hinged on the following aspects:

- Arterial network cartographic analysis
- Arterial network structure classification
- Traffic flow recordings.

The urban area was first subdivided into three zones:

- Central - Consisting of the grid squares that encircle the old town district.
- Semiperipheral - Consisting of the area immediately surrounding the central zone.
- Peripheral - Consisting of the remaining urban area up to the city boundaries.

For the arterial network cartographic analysis the following were considered:

- Number of lanes
- Road section width
- Road section types
- Traffic light system

On concluding the survey, two differently sized graphs were prepared, representing the primary arterial network:

The first included 500 links, 290 grid nodes and 290 Km of roads.

The second, included 1110 links, 650 grid nodes and 430 km of roads.

After accurately examining the two graphs it was decided to use the first approximation graph.

Subsequent on-the-spot surveys have resulted in the final graph with 334 nodes, 581 links and 295 km of roads.

Graph links are identified by two nodes which characterize the link extremes.

Next, within each grid square the following were determined :

- Single link lengths
- Pertinent area
- Road section type and number of lanes for each traveled way
- Total number of accesses
- Number of traffic lights included in each link.

The arterial length in km was calculated for the primary network, i.e., the main traffic ways, and for the secondary network, i.e., local traffic ways.

The secondary network estimates for each grid square were obtained by assigning to each an equivalent length or "radius" depending on the

zone to which they belonged and considering that in the central district the primary network is much denser than in the semi-peripheral and peripheral zones.

The basis for definition of the equivalent radius of each grid square was to divide the area of the latter by the primary network length.

However, considering the approximations that must be accepted for model inputs the following average equivalent radii were established for the grid squares of each zone :

- Central - R = 150 meters
- Semiperipheral - R = 250 meters
- Peripheral - R = 350 meters

The overall length in km of the secondary network resulted to be 78 km.

The subdivision of the equivalent radii into micro-squares in the central zone was done along the same concepts adopted for the primary network, that is, in this case, dividing the equivalent radii by 9.

Traffic flow evaluation was made by:

- Analyzing the data obtained from Research Institutes and Public Administrations
- Comparing and integrating with the data recorded experimentally

in the sample areas.

The measuring areas were divided in 12 groups according to

- Zone location
- Road type
- Number of lanes

Total daily traffic flow average was calculated for the 12 groups.

However, as model inputs must be flow data referred to light vehicles only, from the recorded results a further computation was made to arrive at percentage subdivisions of light and heavy vehicles for the three city zones.

Multiplication of the total daily flow averages by the light vehicle percent averages gave the daily flow values for the light vehicles only that were assigned to the links belonging to each of the 12 groups.

After assigning to each link its own daily flow value, the hourly flow rates were calculated. To this end, the percent hourly subdivisions of the flow rates determined for the sampling areas. (°°)

The percent average subdivisions were calculated for each of the three zones.

(°°) Data supplied by the Municipal Tramway Service for 1973-74 were used.

The flow hourly rates were obtained by taking the flow daily rates of each link and multiplying them by the vehicle percent hourly subdivision of the zone to which each link belonged.

The vehicle park composition survey was conducted from statistical data supplied by the Turin Automobile Club and from FIAT/ANFIA vehicle registration records.

The vehicle park was subdivided into 9 classes:

- 3 age groups: 1968-69; 1970-72; 1973-74
- 3 piston displacement groups: below 1000 cc, 1000 to 1500 cc, over 1500 cc

The outcome of the data so classified is shown in Table 2.

The information on the composition of traffic, determined in the single recording stations of the Turin arterial network, was instead processed to obtain the following data for every recording station:

- Average matrix for percent values
- Matrix of the average percent values for each of the three Turin zones.

TAB. 2 - PERCENTUAL COMPOSITION OF TURIN CIRCULATING FLEET.

DISPL. CC / REGISTR. YEAR	< 1000	I000/1500	> 1500	TOTAL
1973–74	22	17	1	40
1970–72	21	16	2	39
1968–69	15	5	1	21

Next, taking the flow hourly rates of each link and multiplying them by the final matrix of the link zone, the 9 flow values according to the 3 engine capacity and 3 age groups were obtained, for every link and every hour.
The date for all links were entered on perforated cards.

The secondary network traffic information was obtained by processing the data on motorized mobility contained in a survey available from the Turin Municipality.

For every hour and every grid square of Turin, the motorized mobility over secondary network routes was quantified. As basic hypothesis it was accepted that every motorized movement within the investigated area starts from a secondary network, proceeds along the primary network and ends again on the secondary network.

From this it ensues that the number of movements over the secondary network, for each grid square, is the same as the sum of trip departures and arrivals.

In the study mentioned above the Turin area was subdivided into 26 zones, 20 of which include the city of Turin while the remaining 6 cover the adjacent towns.

Departure trips were calculated using the hourly distribution of internal trips departures.

Arrival hourly distribution was calculated by considering the total number of car trips and the hourly percentage subdivision of the internal trips arrivals.

A further hypothesis was then introduced regarding the genesis of trips inside our area.

The hourly trips were subdivided, for the 20 zones of the city of Turin, on the basis of the percentage of residents and outsiders (entering the zone on account of occupational activities) for each individual zone. In particular, it was assumed that :

- From 7 a.m to 10 a.m departures are generated by residents and arrivals by outsiders
- From 10 a.m to 5 p.m departures and arrivals are shared 50-50 by residents and outsiders
- From 5 p.m to 9 p.m departures are generated by outsiders and arrivals by residents.

Finally, the hourly trips of each of the 20 zones were assigned to the different grid squares proportionally to the mesh area belonging to each zone.

4.2.2 Specific Emissions

The specific emissions of the vehicles in circulation were determined as follows:

- Definition of the driving modes characteristic of the city of Turin.
- Selection of sample vehicles representative of the vehicle park.

Submittal of sample vehicles on engine test stand to the defined driving modes and emission measurements.

The study for the definition of the driving modes for the city of Turin was carried out on the basis of an investigation made on the utilization of mechanical units during trips in urban areas.

Scope of such investigation was to the driving mode representative cycles in some Italian cities.

The study for Turin was carried out by direct determinations on 18 urban routes. These routes were so selected as to cover the largest possible extension of the urban area and to be, individually, of good significance.

Fifteen groups of routes were preliminarily examined. These groups consisted of 481 routes as detailed here:

Group N°	Routes
1	29
2	20
3	15
4	37
5	26
6	49
7	71
8	38
9	41
10,15	36
11	28
12	14
13	16
14	25

of each group the route parameters were considered and it was found that none of the parameters in question characterizes the individual groups in a significant manner. Subsequently, the chi-square homogeneity test was performed in different ways using appropriate Fortran programs on a UNIVAC-1108 computer.

The first results obtained revealed that the following parameters: driver and weekday, have a very scarce impact, or almost no impact at all, on the composition of the different groups. In other words the composition of the groups is independent of these parameters.

The route type and the starting time were then considered and the routes were divided into two groups :

- Peripheral routes
- Central routes

The hours were divided into peak and off-peak traffic hours.

By keeping the non-central routes fixed and by varying the peak traffic hours it was found that χ^2 ranges from 239 to 282. This fact demonstrates that the groups are not homogeneous and, first of all, that the starting time parameter is not significant.

In a further processing a trial was made by changing the number of routes considered non-central while keeping fixed the peak traffic start in hours : it was found that χ^2 ranges from 69 to 226.

This means that groups homogeneity is closely bound to the route type and confirms once again that the starting time of a route is not significant.

Furthermore, starting times are kept fixed and route division is changed χ^2 ranges from 65 to 245.

These results are a further proof that the composition of groups is strictly bound to the routes and that the starting time has no impact, even with this new subdivision of the routes into the three groups.

On the basis of what said above, the representative route of Turin was obtained by assigning the same weight to all the homogeneous route groups.

Statistical processing of the cycles relevant to the different areas led to the definition of a typical cycle-illustrated in the three charts-for each area (see Figs. 7, 8, 9).

Such driving modes have been coupled to the urban area partitioning zones.

The search for the sample vehicles representative of traffic composition was carried out by FEEMAS on the basis of 9-class rating performed as said previously.

All in all, 30 vehicles of the different classes have been chosen.

The measurement of the specific emissions from the sample vehicles was made by repeating on chassis dynamometer for each sample vehicle, the three typical cycles of the city of Turin.

The results of the measurements of CO emissions taken on the sample cars have been repeated in Tab. 3.

5. Outline of Mathematical Model Input Data Collection and Processing

Input data have all been entered on 8500 perforated cards and processed in a UNIVAC 1110 computer.

The calculation program permits the following model output to be obtained:

ACTUAL DRIVING CYCLES IN TURIN

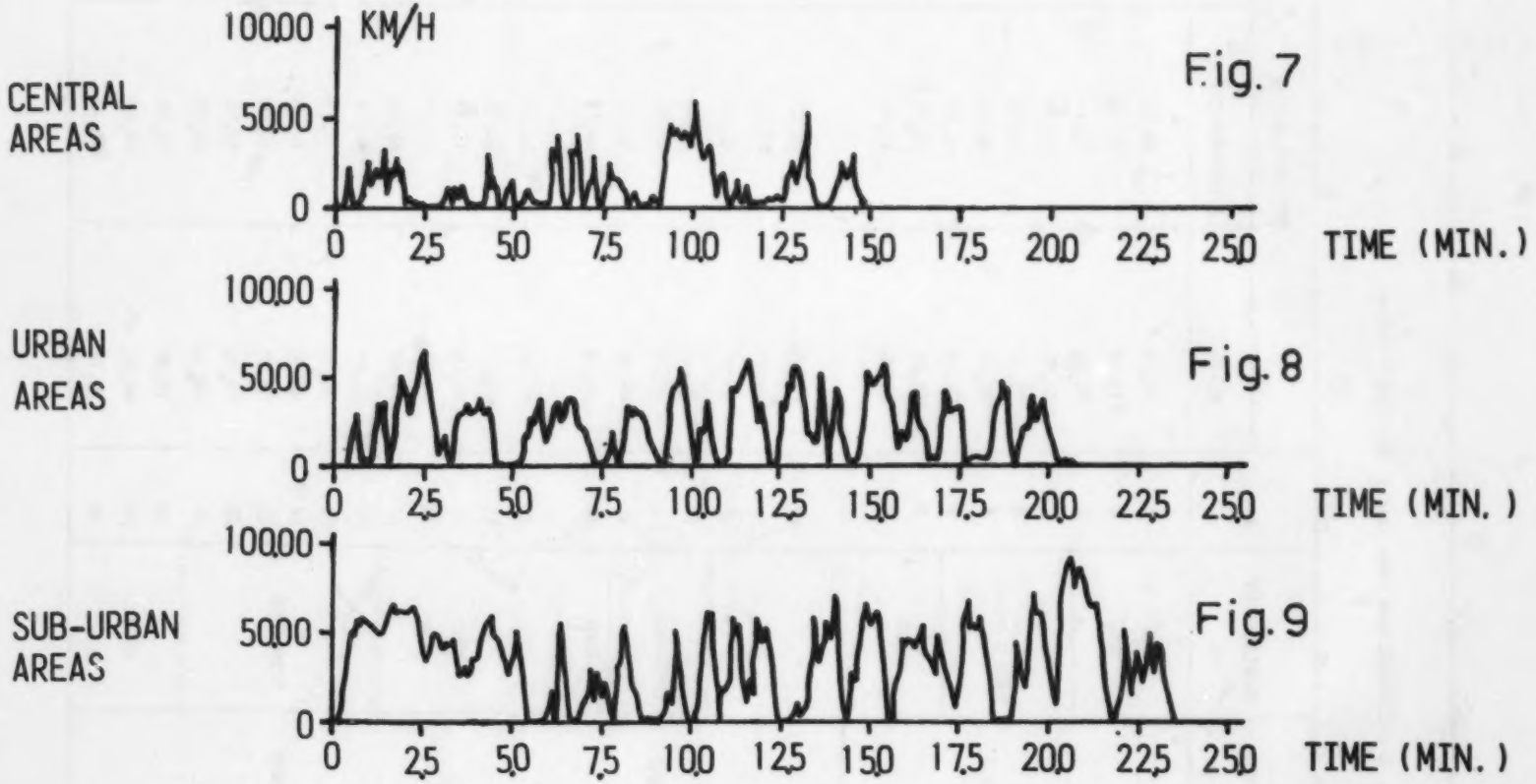


Fig. 7

Fig. 8

Fig. 9

TAB. 3 – CO EMISSIONS FROM SAMPLE VEHICLES (GR/KM)

REG. YEAR	DISPLACEMENT CC	CAR	DRIVING CYCLE		
			CENTRAL	SEMIPERIPHERICAL	PERIPHERICAL
1973–1974	1000	1	36,23	24,70	25,39
		2	47,17	32,16	22,94
		3	36,24	25,11	21,24
	1000 + 1500	4	64,92	45,29	36,64
		5	73,65	33,19	24,93
		6	92,26	96,44	65,46
		7	101,19	62,88	56,59
	1500	8	84,89	42,73	34,97
		9	56,10	43,40	33,45
1970–1972	1000	10	67,00	18,42	11,03
		11	61,17	27,76	48,41
		12	83,35	36,57	33,01
	1000–1500	13	82,10	56,04	40,65
		14	83,27	48,06	32,87
		15	85,30	40,30	28,40
	1500	16	46,18	24,11	29,94
1968–1969	1000	17	42,42	25,16	18,98
		18	48,99	28,34	19,64
		19	34,00	16,30	14,60
		20	45,53	33,03	24,22
		21	77,66	43,50	30,47
	1000–1500	22	67,64	45,24	39,22
		23	60,74	26,19	32,55
		24	80,38	44,29	32,83
		25	65,70	38,60	39,90
		26	79,10	43,40	31,10
		27	80,38	44,29	32,83
	1500	28	73,39	44,50	31,43
		29	99,88	68,19	60,58
		30	75,74	43,86	35,31

- Printing of hourly CO concentration for each receptor point on the basis of typical hourly input data and of the relevant coordinates.
- Configuration of urban area division grid with pollutant concentration each square.
- Map representation of iso concentration curves.

6. Model Application - Check and Processing of Results

Processing of the mathematical model was so programmed as to have available a pollution level pattern as follows:

- Under the present urban traffic conditions, assuming they are representative of the various experimental driving modes.
- In the assumption of a pedestrianized island in the city center.

6.1 Assessment of Model Results Validity

In order to verify the validity of mathematical model outputs, a comparison was made, in the time span considered, between the calculated pollution levels and those recorded at the Monitoring Stations.

As can be seen on the charts of Fig. 10 thru 15 and Tables 4 thru 13, the calculated values reliably reflect the actual concentration level patterns on a typical day; pollution peak levels occur at peak traffic hours and minimum levels at off-peak traffic hours.

The model showed its ability to perceive such variations and to express them in terms of CO concentrations sufficiently close to reality.

As far as the recorded deviations are concerned, in some cases they may be of a certain extent but on the average their values remain within acceptable limits.

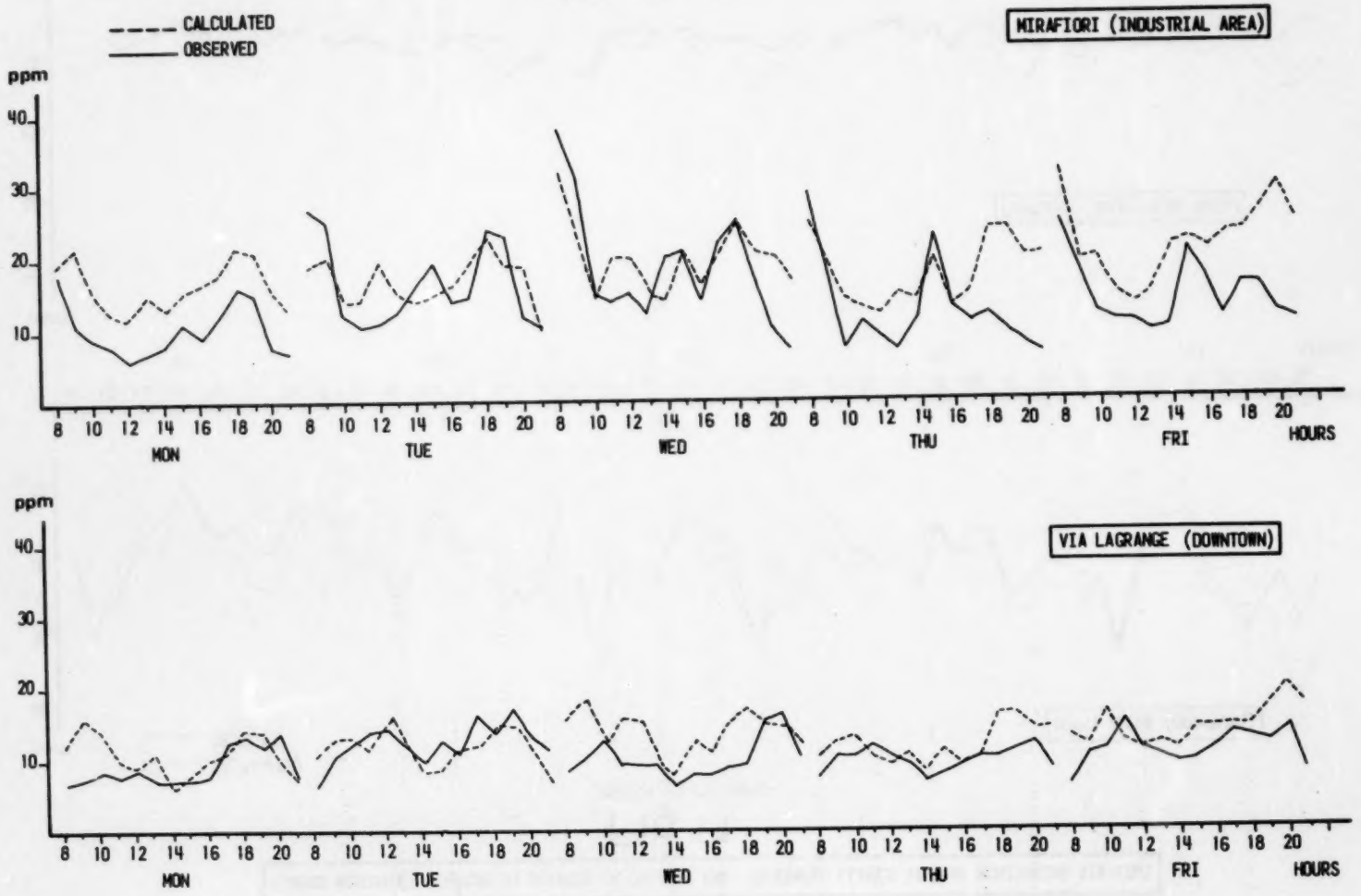
On the basis of the results obtained from the first series of processing, a program was set up for further use of the model to simulate particular pollution conditions such as those consequent to the adoption of a pedestrianized island in the city center.

The results of processing performed assuming a pedestrianized island in downtown Turin are of great interest. This simulation proved to be suitable for evaluating the ecological impact of an urban planning provision that the Public Authorities looked upon with increasing favor to solve the problems of traffic in the urban areas.

CARBON MONOXIDE: COMPARISON BETWEEN CALCULATED AND OBSERVED LEVELS AT FIAT MONITORING STATIONS

Fig. 10

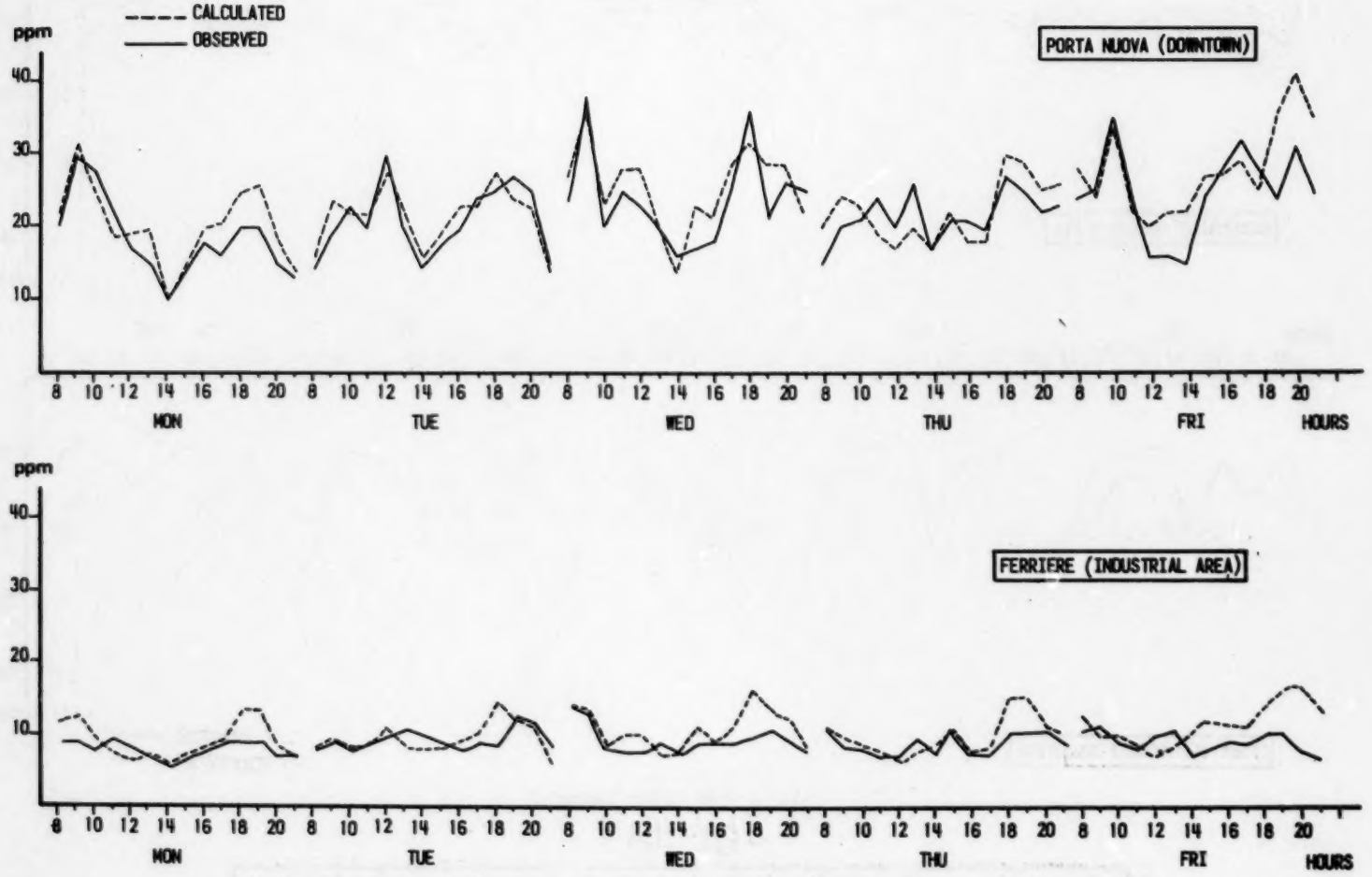
JANUARY 13/17 - 1975



CARBON MONOXIDE: COMPARISON BETWEEN CALCULATED AND OBSERVED LEVELS AT FIAT MONITORING STATIONS

Fig. 11

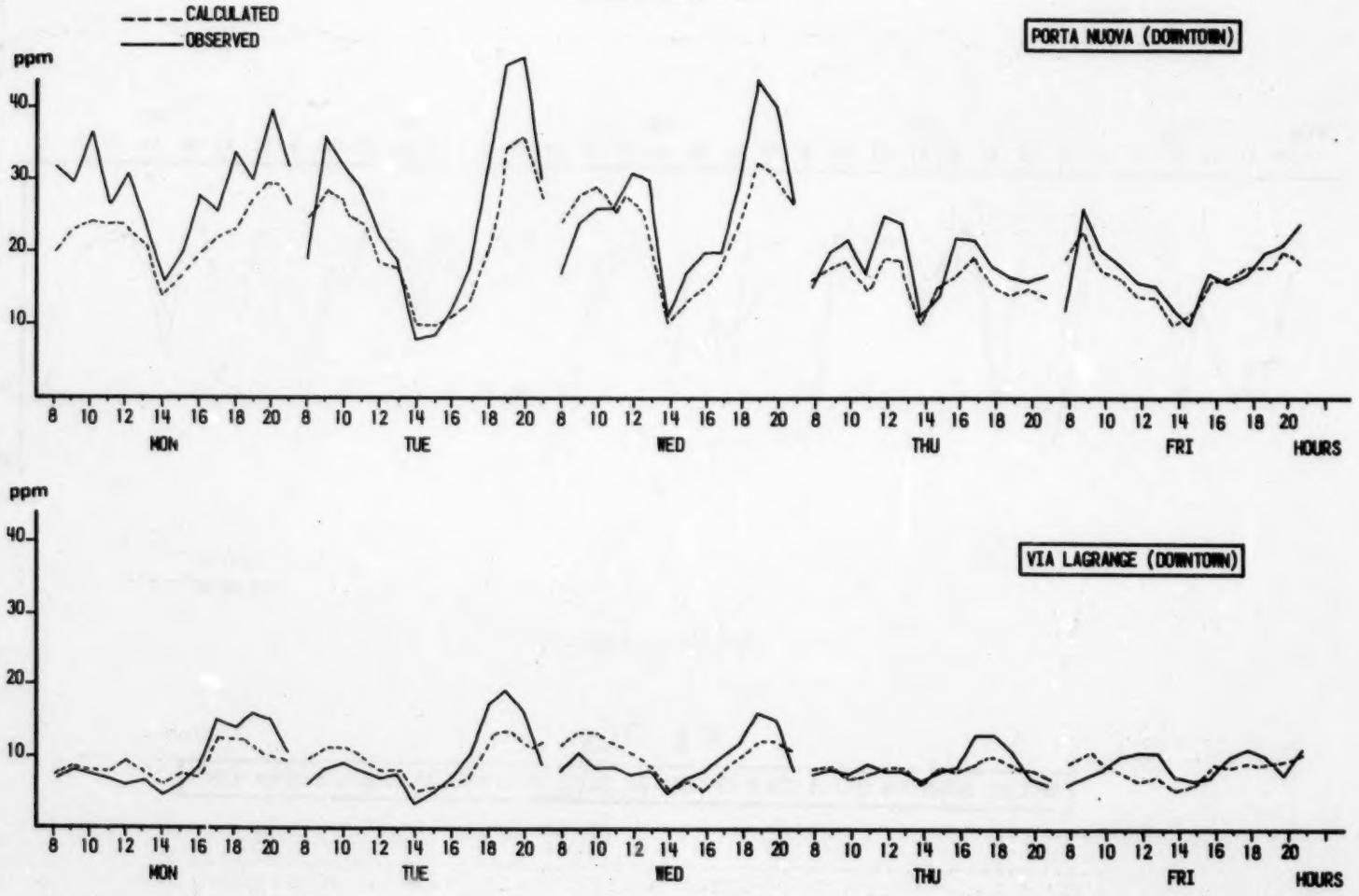
JANUARY 13/17 - 1975



CARBON MONOXIDE: COMPARISON BETWEEN CALCULATED AND OBSERVED LEVELS AT FIAT MONITORING STATIONS

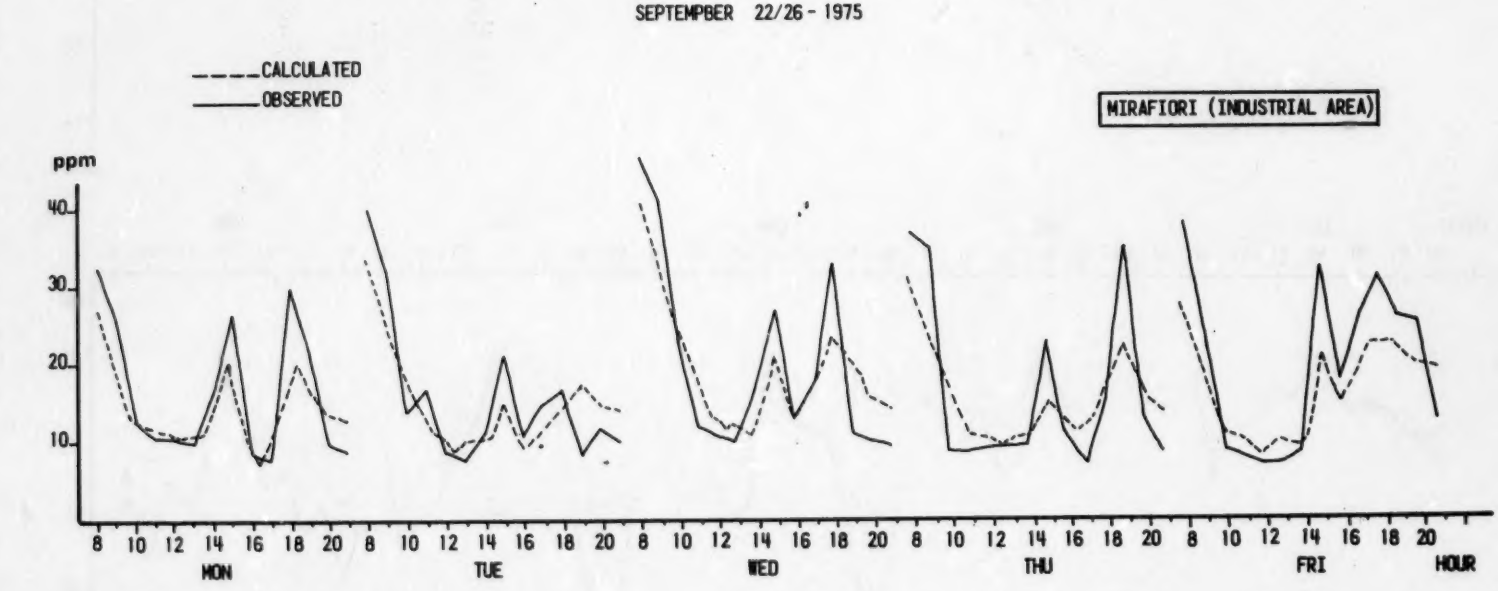
Fig. 12

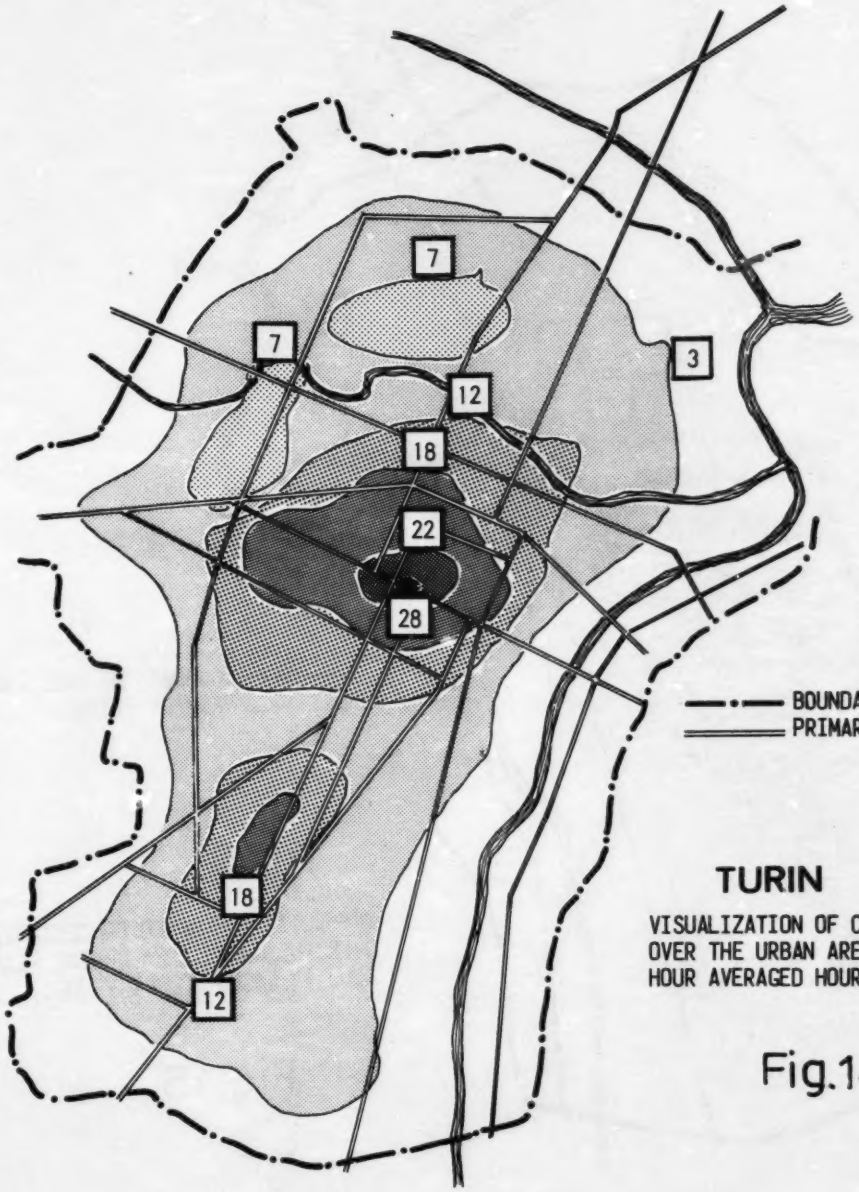
SEPTEMBER 22/26 - 1975



CARBON MONOXIDE: COMPARISON BETWEEN CALCULATED AND OBSERVED LEVELS AT FIAT MONITORING STATIONS

Fig. 13

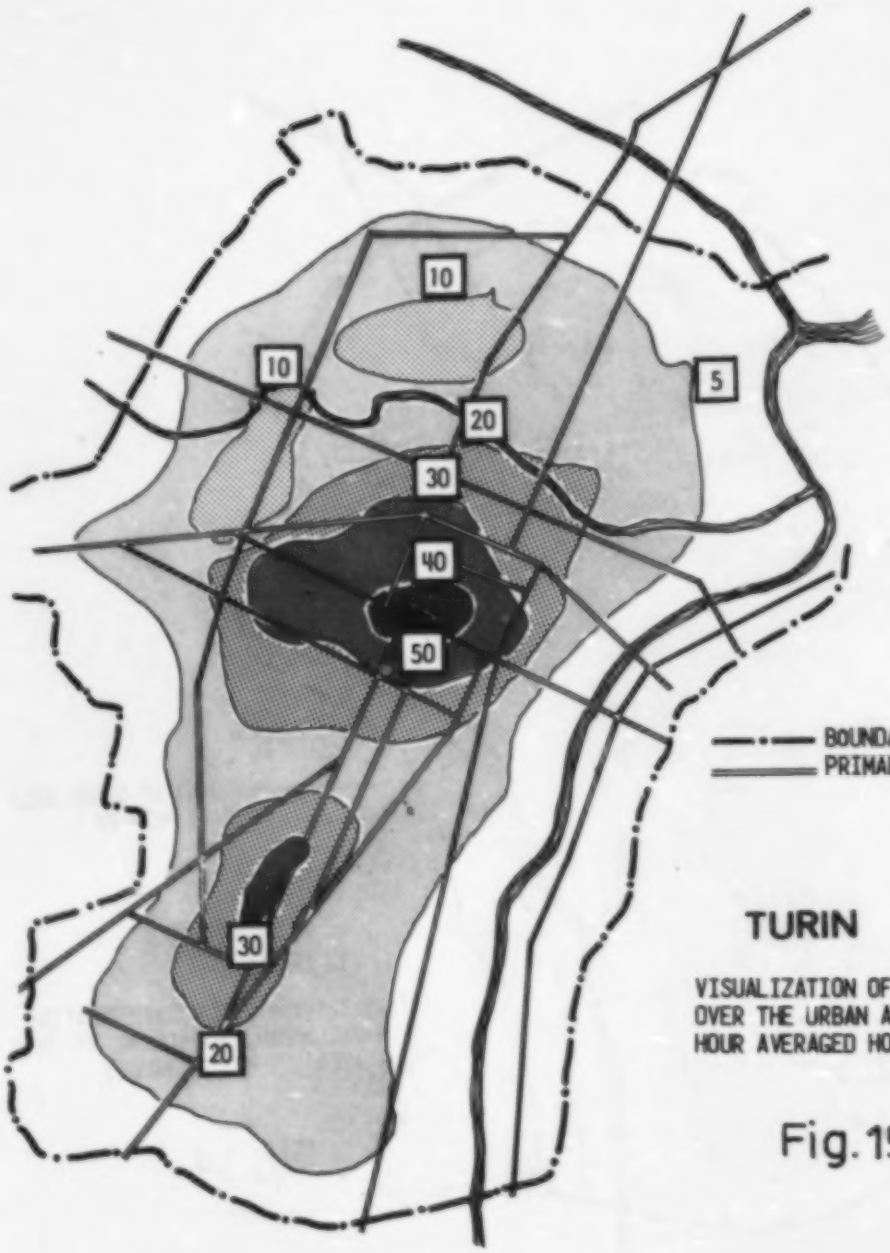




TURIN

VISUALIZATION OF CO CONCENTRATION OVER THE URBAN AREA DURING OFF-PEAK HOUR AVERAGED HOURLY VALUES

Fig.14



TURIN

VISUALIZATION OF CO CONCENTRATION OVER THE URBAN AREA DURING PEAK HOUR AVERAGED HOURLY VALUES

Fig. 15

TAB. 4 - CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

January, Monday 13, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	19	12,5	21	11	17,5	7	20	8
9	21	16	30	13	10,5	7,4	28	8
10	15	14	31	13	9	8	27	7
11	13	10	24	11	8	7,5	2,5	9
12	11	9	18	8	6,5	8,5	17	8
13	15	11	19	7	7,5	7	15	7
14	12	6	19	7	8	7,2	10	6
15	15	7	10	6	11	7,3	14	7
16	17	10	12	7	9	7,5	17	7,5
17	21	11	18	7	11,5	12,5	16	8
18	20	13	20	8	15,5	13	18	8
19	21	13	23	12	14,5	12	18	8
20	15	10	24	12	7,8	13,5	15	7
21	12,5	7	19	8	7,4	7,5	13	7

TAB. 5 - CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

January, Tuesday 14, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	18	10	15	7,6	27	6,4	14	7,6
9	20	12	22	8	25	10,2	16	8
10	15	13	21	7	12	12,5	21	7,5
11	13	11	21	8	10,5	14	20	8
12	13	15	26	10	10,8	14,5	29	10
13	19	16	23	7	12,5	12	18	11
14	15	12	17	7	15,7	10	15	10
15	13	8	18	7	19	12,5	17	8
16	16	8	21	8	13,2	10,5	20	7,6
17	15	11	21	10	14	16	23	8
18	20	11	25	13	23,8	13,6	24	8
19	22	15	22	12	23	17	26	12,5
20	18	15	21	11	11,4	13,8	23	12
21	17	7	12	6	10	11,8	13	8

TAB. 6 - CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

January, Wednesday 15, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	31	15	26	14	38	8	22	14
9	22	18	35	13	32	10	38	12,8
10	13	13	24	9	14	12,5	20	8
11	20	15	26	10	13	9	22	7,8
12	20	15	26	10	14,5	8,9	21	7,5
13	15	10	20	7	12	8,8	20	8,3
14	14	8	14	7	20	6,4	15	7,5
15	20	13	21	11	21	7,5	16	8
16	16	11	19	10	13,7	7,5	17	9
17	25	15	28	11	22,4	8,7	25	9
18	20	16	30	15	25	8,8	35	10
19	20	15	28	12	15	15	21	11
20	19	16	28	12	10	16,3	24	9
21	16	10	22	8	7	10	23	7,8

TAB. 7 - CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

January, Thursday 16, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	24	10	20	11	28,8	7,4	15	11
9	19	12,5	22	10	15	10	19	8,3
10	13	13	21	8	7,4	10	20	8
11	12,5	10	19	8	10,5	12	22	7,3
12	12	9	17	7,5	9	10	18	7,3
13	15	11	18	7,5	7	8,8	25	9,5
14	14	8	17	8	11	7	15	7,5
15	20	11	20	11	22,7	7,7	20	11
16	12,5	9	18	7,5	12,5	9	20	7,5
17	15	10	18	8	10,5	10	19	7,5
18	23	16	28	13	11,8	10	26	10,8
19	24	16	27	13	9	11,3	24	11
20	20	14	24	12	7,5	12,2	22	11
21	20	14	25	11	6,5	8	23	8

TAB. 8 - CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

January, Friday 17, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	32	12,5	28	12,5	25	6,6	23	10,5
9	20	12	24	10	17,5	10,2	24	11
10	20	16	33	10	11,3	11	34	8,5
11	15	12,5	25	8	10,5	15	22	8
12	12,5	11	21	7,5	10,5	11	17	10
13	15	11	22	8	9	10	18	8,5
14	21	12	22	11	10	9	16	7
15	21	14	28	11	20,5	9,5	25	8
16	20	14	29	11	17,5	11	28	9
17	22,5	14	29	11	11,5	13	30	8,8
18	22,5	14	25	13	15,5	12,5	28	10,2
19	26	17,5	36	15	15,4	12	25	10,7
20	30	18	40	15	12	14	29	7,8
21	25	17,5	36	12,5	10,5	8	26	7

TAB. 9 - CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

September, Monday 22, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	26	7,5	20		32	7	32	
9	20	8	22,5		27,5	7,8	30	
10	12,5	7,5	24		12,5	7,5	36	
11	11	7,5	23,5		10	7	27	
12	11	9	23,5		10	6	31	
13	11	7,5	21		9,8	6,8	25	
14	11	6	14		15	4,8	17	
15	20	7,5	16,5		26,4	6	20	
16	9	6,5	19,5		8	8	27,5	
17	10	10	22		7,5	14,8	25	
18	17,5	12,5	22,5		29	13,8	33	
19	15	12,5	27,6		22,5	15,8	30	
20	12,5	10	29		9	15	40	
21	12,5	9	26		8,5	10,6	32,5	

TAB. 10 - CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

September, Tuesday 23, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	33	10	25		39,5	6,5	20	
9	25	11	28		32	8	36	
10	17,5	11	27,5		13,5	8,8	28	
11	15	10	24		16,3	7,8	22,5	
12	10	8	18		8,5	7	18	
13	10	8	17,5		7,5	7,5	7,5	
14	10	5	10		11,3	3,8	8	
15	15	6	10		21	5	12,5	
16	9	6	11		10,8	7,5	17,5	
17	11	6,5	13		14,5	10	32,5	
18	14	12,5	20		16,3	17	46	
19	17,5	13	35		8	19	47,5	
20	13	12,5	36		11,3	16	30	
21	13	11	27,5		10	8,8	30	

TAB. 11 CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

September, Wednesday 24, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	40	11	23		46	7,8	17	
9	30	13	27,5		41	10,5	23,8	
10	23	13	28		22,5	8	26	
11	17,5	11,5	25		11,3	8	26	
12	12,5	10	27,5		10	7,5	31	
13	12	9	20		9,8	7,8	30	
14	12,5	6	10		17,5	5	11,8	
15	20	6,5	13		26,3	7	17	
16	12,5	5	15		12,5	8	20	
17	17,5	7,5	18		17,5	10	20	
18	22,5	10	25		32,5	12	29	
19	20	11	32,5		10,8	16	43,8	
20	15	12,5	30		10	15	40	
21	13	11,5	27,5		9	8	27	

TAB. 12 - CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

September, Thursday 25, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	30	8	18		36,5	7,5	15	
9	22,5	8	17,5		34,8	8	20	
10	17,5	7,5	18		8	7,8	22	
11	10	7,5	15		8	9	17	
12	10	8	19		8,5	7,9	25	
13	10	8	19		8,8	7,9	24	
14	11	6	10		9	7	11,8	
15	15	8	16		22,5	8	14	
16	12,5	7,5	17		11	8,5	22	
17	12,5	9	19		7	13	21,8	
18	17,5	10	15		15	13	17,5	
19	22,5	9	14		34,6	11	14,8	
20	15	8	15		12,5	7,5	16,2	
21	12,5	7,5	13		8	6,8	17	

TAB. 13 CHECK OF RESULTS VALIDITY

Comparison between the data calculated with the mathematical model and the data observed at FIAT Monitoring Stations

September, Friday 26, 1975

Hour	Calculated values (Differentiated Cycles) ppm				Observed values ppm			
	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE	MIRAFIORI	LAGRANGE	P. NUOVA	FERRIERE
8	27,5	9	19		37,5	6,8	12	
9	17,5	10	22,5		22,5	7,5	26,3	
10	11	9	17,5		8	8,5	20	
11	10	7,5	16		7,5	10	17,5	
12	7,5	6,5	13,5		7	10,8	15,8	
13	10	7,5	13,5		6,8	10,5	15	
14	9	5	10		8	7,5	12,5	
15	20	6	12,5		31,5	7	10	
16	15	8	16		17,5	7,5	17	
17	12,5	9	16		25	10	15,8	
18	22,5	10	17,5		31	11,5	17,5	
19	22,5	9	17,5		25,5	10,3	20	
20	20	9	20		25	7,8	21,5	
21	19	7,5	18		12,5	11	24	

It was therefore assumed that private vehicle traffic flow would be banned in 20 squares of the grid corresponding to the city center and that, therefore, emissions from vehicles would be eliminated. Two simplifying assumptions were made:

- That the "public transport" component does not constitute an appreciable CO pollution source in the pedestrianized island.
- That banning of private cars in this area does not result in their redistribution in the surrounding areas with consequent alteration of the present traffic flow rates.

Processing was made by evaluating the pollution levels that can be reached during a peak traffic hour of a typical day.

Processing results have shown that in the pedestrian zone there would be an 80-90% decrease in the pollution rate with respect to the actual values (see Fig. 16-17 and Table 14).

Residual concentration levels would be minimum (1.6 to 3.4 ppm).

In some boundary squares the recorded decrements are lower (50-60%) in as such as these areas are evidently affected by the emissions of nearby areas where traffic is allowed.

In the areas next to the pedestrian zone that are little affected by the provision, pollution levels are almost unchanged with respect

TURIN DOWNTOWN AREA

Fig. 16

DISTRIBUTION OF CO CONCENTRATION PEAK-HOUR UNDER NORMAL CONDITIONS

5.0	5.0	5.0	24.7	27.8	28.5	4.9	4.9	5.8	10.6	10.5	10.5	6.9	6.3	6.3
5.0	5.0	5.0	24.7	27.8	28.3	4.9	4.9	5.8	10.6	10.5	10.5	6.3	6.3	6.3
5.0	5.0	5.0	24.7	26.2	29.0	4.9	5.0	5.8	10.8	10.6	10.6	6.5	6.5	6.5
6.3	6.5	6.6	10.1	11.2	11.9	4.6	4.9	5.2	7.1	7.0	7.0	10.5	10.4	10.4
6.3	6.5	6.6	10.1	11.2	11.9	4.6	4.9	5.2	7.1	7.0	7.0	10.5	10.4	10.4
6.3	6.6	6.6	10.1	10.8	11.4	4.8	4.9	5.1	7.2	7.2	7.2	10.8	10.4	10.4
13.6	14.3	14.4	7.4	7.1	7.5	13.7	13.7	13.7	12.9	12.4	12.4	4.7	4.4	4.4
14.4	15.6	15.8	7.8	6.8	6.8	15.2	15.2	15.0	13.9	13.1	13.1	8.7	8.5	3.5
14.5	15.8	16.1	8.3	7.0	6.8	15.7	15.6	15.2	13.4	13.1	13.1	8.4	8.4	8.4
4.2	4.0	3.9	6.7	6.7	6.9	22.5	22.6	22.5	23.3	23.3	23.3	5.1	4.9	4.9
4.1	4.0	3.6	6.6	6.5	6.5	21.7	21.6	21.5	22.3	22.2	22.2	4.9	4.8	4.8
3.8	3.7	3.5	5.8	5.7	5.7	14.2	14.1	14.0	14.9	14.8	14.8	5.3	5.2	5.2
8.4	3.3	3.1	4.7	4.5	4.5	8.2	8.1	3.0	4.0	3.9	3.9	6.0	5.9	5.8
3.6	3.6	3.3	4.6	4.4	4.4	8.1	8.1	3.0	4.0	3.8	8.8	5.7	5.0	5.6
6.8	6.7	6.5	8.7	3.5	3.5	8.4	8.8	3.2	8.8	8.5	8.5	8.8	3.7	3.7
11.7	11.6	11.4	2.4	2.2	2.2	8.8	8.7	8.6						
11.3	11.2	11.1	2.3	2.2	2.2	3.7	3.7	3.5						
6.6	8.6	8.6	2.0	2.0	2.0	8.1	8.1	2.9						

HYSTORICAL CENTRE

TURIN DOWNTOWN AREA

Fig. 17

DISTRIBUTION OF CO CONCENTRATION DURING A PEAK-HOUR TRAFFIC BAN INSIDE HYSTORICAL CENTRE

5.0	5.0	5.0	24.7	27.8	28.3	4.9	4.9	5.6	10.6	10.5	10.5	6.3	6.3	6.3
5.0	5.0	5.0	24.7	27.8	28.3	4.9	4.9	5.6	10.6	10.5	10.5	6.3	6.6	6.9
5.0	5.0	5.0	24.7	28.2	29.0	4.9	5.0	5.8	10.8	10.6	10.8	6.5	6.5	6.5
6.3	6.5	6.6	10.1	11.2	11.9	4.8	4.9	5.2	7.1	7.0	7.0	10.5	10.4	10.4
6.3	6.5	6.6	10.1	11.2	11.9	4.8	4.9	5.2	7.1	7.0	7.0	10.5	10.4	10.4
6.3	6.5	6.5	10.1	10.8	11.4	4.8	4.6	2.8	2.8	7.2	7.2	10.8	10.4	10.4
13.6	14.3	14.4	7.4	7.1	7.5	12.6	1.9	1.6	2.1	3.4	3.4	4.7	4.4	4.4
14.4	15.6	15.8	7.8	6.8	8.8	18.1	1.8	1.7	2.0	3.3	3.3	3.7	3.5	3.5
14.5	15.8	16.1	8.9	7.0	6.8	2.5	1.6	1.7	2.8	12.2	12.2	8.4	3.4	3.4
4.2	4.0	3.9	6.7	6.6	6.9	10.3	2.0	2.0	10.6	23.9	23.9	5.1	4.9	4.9
4.1	4.0	3.8	6.6	6.5	6.5	21.7	9.3	9.2	22.3	22.2	22.2	4.9	4.8	4.8
3.6	3.7	3.5	5.8	5.7	5.7	14.2	14.1	14.0	14.9	14.8	14.8	5.9	5.2	5.2
3.4	3.3	3.1	4.7	4.5	4.5	3.2	3.1	3.0	4.0	3.9	3.9	6.0	5.9	5.9
3.6	3.6	3.3	4.6	4.4	4.4	3.1	3.1	3.0	4.0	3.9	3.9	5.7	5.6	5.6
6.8	6.7	6.5	3.7	3.5	3.5	3.4	3.3	3.2	3.6	3.5	3.5	3.8	3.7	3.7
11.7	11.6	11.4	2.5	2.2	2.2	3.8	3.7	3.6						
11.3	11.2	11.1	2.3	2.2	2.2	3.7	3.7	3.5						
8.8	8.6	8.6	2.0	2.0	2.0	3.1	3.1	2.9						

HYSTORICAL CENTRE

TAB. 14

CO concentrations inside pedestrianized area ppm			CO concentrations at the boundary of pedestrianized area ppm		
Grid	Normal conditions	Ban of traffic	Grid	Normal conditions	Ban of traffic
N 13.1	5,1	2,3	N 13.2	5,2	5,2
O 13.1	7,2	2,8	O 13.2	7,1	7,1
N 14.1	13,7	1,9	N 13.3	4,9	4,6
N 14.2	13,7	1,6	O 13.3	7,2	7,2
O 14.1	12,3	2,1	N 14.8	13,7	12,6
O 14.2	12,4	3,4	O 14.6	12,4	3,4
N 14.3	15,2	1,8	N 14.9	15,2	13,1
N 14.4	15	1,7	O 14.7	13,1	3,3
O 14.3	13,3	2	O 14.8	6,8	6,8
O 14.4	13,1	3,3	O 14.9	13,1	12,2
N 14.5	15,7	2,5	N 15.6	6,9	6,9
N 14.6	15,6	1,6	O 15.2	23,3	23,3
N 14.7	15,2	1,7	N 15.7	21,7	21,7
O 14.5	13,4	2,8	O 15.3	22,3	22,3
N 15.1	22,8	10,3	N 15.8	14,1	14,1
N 15.2	22,6	2	N 15.9	14,0	14,0
N 15.3	22,5	2			
O 15.1	23,3	10,6			
N 15.4	21,6	9,8			
N 15.5	21,5	9,2			

to the present levels.

This fact can be explained with the rapid diffusion of CO whose recorded values are practically negligible when its sources are far from the monitoring point CO amounts increase instead considerably when the sources are next to the receptor point.

The conclusions that can be drawn from this last processing approach can be of great interest because the methods adopted so far the control of atmospheric pollution - at least that from mobile sources - were univocally directed toward an increasingly restrictive limitation of emissions.

The more stringent the emission limits enforced the more economically and tecnically exacting will be this policy that is perhaps the easier to implement.

Moreover, it is impossible to foresee whether, with traffic density at the present level or increased, emission abatement provisions may lead to acceptable air quality standards.

It is in fact possible that the planning structure of urban areas feature congested traffic areas or bottlenecked junctions that will lead to higher carbon monoxide standards even with more stringent emission limits.

On the other hand, it is possible that in some urban areas characterized by a rationally structured road network, the standards be already met with present urban planning and, therefore, the adoption of even more stringent limits would be unjustified.

The study of urban planning provisions aimed at environmental protection through a realistic policy corresponding to the actual urban areas requirements is therefore particularly important.

The adoption of reserved zones and of one-way thorough fares as well as a more rational distribution of traffic, positively contribute to the amelioration of the environment.

Care shall obviously be taken not to alter the socioeconomic balance of the urban system.

7. Analysis of Model Sensitivity

The analysis of model sensitivity permits an assessment of the effects caused by the variation of model input parameters on the output.

The smaller the output variation in relation to a large variation of an input parameter, the more the output will be independent of this parameter.

Analysis of sensitivity was made for each monitoring station by calculating the CO concentration levels from 5 to 6 p.m. with a 1 m/s

wind speed but changing the following parameters:

1. Wind direction

2. Mixing depth

3. Stability class

Values calculated with mixing depth h = 342 m (September), with the same wind speed and stability class A were assumed as reference.

7.1 Wind Direction

Calculation of CO concentrations, carried out both for a single wind speed and for eight different directions shows that, with all other inputs at par, the maximum recorded variation with respect to the reference values is $\pm$ 2 ppm.

It can therefore be inferred that model sensitivity to this parameter is minimum.

7.2 Mixing Depth

With stability class A and constant wind speed, it can be observed that:

- for h = 30 mt a max. plus deviation of 15 ppm (downtown) from the reference values occurs
- for h = 1000 mt a max. minus deviation of 1 ppm is found.

7.3 Stability Class

Stability class B gives concentration values about half those obtained with class A.

Classes B, C and D give concentration values that deviate from the reference values as follows:

- by 1 ppm with h = 30 mt
- from 2 ppm min. (suburban area) to 7 ppm max. (downtown) with h = 1000 mt.

7.4 Wind Speed

The analysis of sensitivity was not made for wind speed inasmuch as the results can easily be inferred from the fact that the CO concentration values calculated by the model are inversely proportional to wind speed.

Since this concentration wind speed correlation low is not observed in reality, a "correction" of wind speed measured was made on the basis of the experimental data.

7.5 Emissions

The relation of direct proportionality with the calculated concentrations applies also to emissions.

From an investigation of the analysis data it appears that the

model responds:

- with high sensitivity to the variations of emission and wind speed parameters
- with low sensitivity to the values of wind direction, atmospheric stability and mixing depth. For this last parameter, in fact, sensitivity in the range of the values normally found (200-600 m) is minimum and tends to increase for decreasing values that are not actually measured in the urban area.

8. Analysis of Error Sources

As can be seen from the comparison between the calculated and measured pollution levels, the mathematical model is sufficiently versatile notwithstanding the great number of parameters on which it is based and the relevant uncertainty limits.

Accordingly, it can be thought that the model, used as a forecasting tool, will provide sufficiently reliable results.

Discrepancies between the calculated and the experimentally measured values can be attributed to some sources of error which can be classified under two categories.

a) Possible inaccuracies of the input data

b) Assumptions for model formulation with regard to the precision

of the input data, it should be noted that since calculated CO concentrations are directly proportional to traffic emissions and inversely proportional to wind speed, these two parameters play a fundamental part in causing errors.

Determination of emissions, based on traffic and specific emission evaluations, may have introduced a source of error both in the calculation of vehicles travelling at different hours and in the representativity of sample vehicles for the experimental measurement of emissions.

Actually, the statistical investigation of traffic flow distribution cannot obviously take into account contingent situations (local traffic bottlenecks, etc.) that are instead detected by pollution monitoring stations.

On the other hand, the analysis of the emission data obtained from direct measurement on sample vehicles shows considerable value consistency for the different sample vehicles. This fact suggests that the error introduced by these inputs in the calculation is very small.

When the meteorological parameters measured by the Monitoring Stations are used as input parameters, an exact representation of the anemological situation of the city is ensured.

From an investigation of the analysis data it appears that even in this case it is not possible to take into account particular local conditions such as turbulence, convective motions due to buildings and ascending currents typical of built-up areas. Also these non-classifiable factors represent an error source. However, the anemological conditions measured by the Stations simulate the real situation better than the data recorded at the airports.

Data from airports are generally used for model application to the urban centers but they are not actually representative of these areas.

On the other hand, the exact reproduction of the local dynamics of pollutant flows is possible only by a micromodel and experimental measurement of local micrometeorologic conditions.

With regard to the other meteorologic parameters, the adoption for Turin of the typical Milan mixing depth values involves, as already said, approximately a 15% error with respect to the values measured in Turin. However, said parameter does not proportionally affect the calculated concentration levels.

The relationship is actually more complex. In particular, for minimum mixing depths under instability conditions, the calculated concentrations, with other parameters at par are almost inversely

proportional to the mixing depth.

For high mixing depths, the calculated concentrations increase rapidly with higher atmospheric stability.

At any rate, model sensitivity to this input parameter is limited with respect to the parameters already analyzed.

The second gross error source can be found in the very model formulation. In general it can be assumed that, because of local turbulence, pollutant diffusion in the urban areas is more rapid than provided by the Pasquill-Gifford functions.

Nevertheless, buildings reduce the volume useful for pollutant diffusion and this is in contrast with what was said previously.

Moreover, the model assumption, that the input parameters are valid for the whole urban area, is clearly inappropriate.

Actually, since the sources next to the receptor are very important for the calculated pollution levels, the stability class and mixing depths values in the areas nearest the receptor point are more important than the values corresponding to the farther areas.

This means that the input data should consider the mesometeorologic conditions in the windward area of each receptor point.

APPENDIX 1

Description of the monitoring systems

For a systematic investigation of air quality in Turin Fiat set up a monitoring network which has been operating since 1971. This network permits availability of statistical data of primary and secondary pollution in places representative of the different urban areas.

The monitoring network consists of :

- three stations equipped with instrumentation for complete determination of the primary pollutants and the meteorological parameters. Significance of the data obtained in these stations is related to their location.

The monitoring stations are situated in:

- V. Lagrange, in the middle of the business district. This street is a typical street canyon with 5.50 m roadway flanked by 25-30 m high buildings. The usually heavy traffic along this street (17,000 vehicles/day with peak traffic of 1,700 vehicles /hr) is slackened by traffic lights.

- At Mirafiori and Ferriere adjacent to high industrial concentrations and large road junctions (51,500 vehicles/day with peak traffic of 4,700 vehicles/hr at Mirafiori; 34,000 vehicles/hr and peak traffic of 3,300 vehicles/hr at Ferriere).
- two CO monitoring stations located in the very central zones of Porta Nuova (77,000 vehicles/day with peak traffic of 6,000 vehicles/hr) and Piazza Statuto (60,000 vehicles/day with peak traffic of 4,500 vehicles/hr).
- One station for complete determination of the primary and secondary pollutants situated on the Mole Antonelliana, in the city center, at 93 m height with possibility of monitoring air at 93 and 145 m height. This station started to operate early in 1974 (Fig. 18).
- Eight stations for monitoring lead at 1,50 m above road level are located in important areas of the urban traffic (road junctions, central and peripheral arterials).

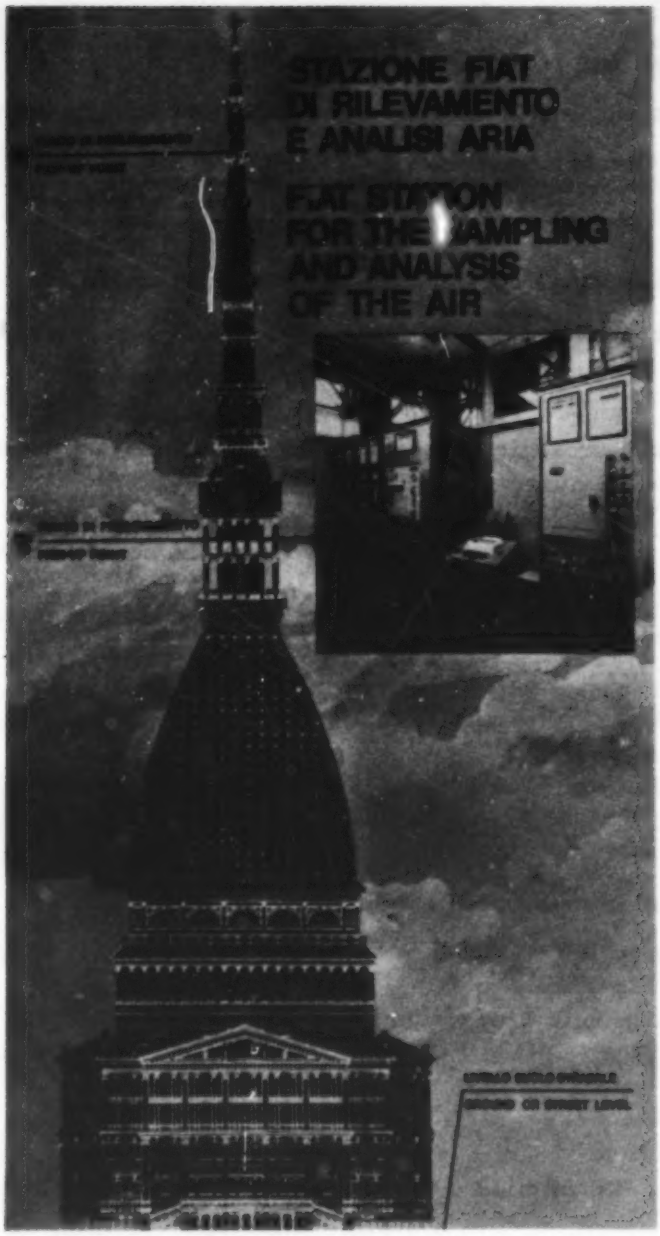

STAZIONE FIAT
DI RILEVAMENTO
E ANALISI ARIA
FIAT STATION
FOR THE SAMPLING
AND ANALYSIS
OF THE AIR

Fig. 18

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